Improving Project Management with Risk Assessments Using Bayesian Estimation

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Introductions

- Your Speaker
- The Audience

Presentation Premise

- **Projects More Likely to Succeed when Project Managers make Good Decisions**
  - **PM's have to make Hard Decisions (and take the heat)**
  - **Many Decisions have Very Little Data (e.g., Safety, Reliability, Research)**
  - ***Why you get the Big Bucks!***
- **Decisions are Always Based on Some Assessment of the Risk of the Decision not Producing the Desired Outcome**
- **Better Risk Assessments produce Better Decisions, and Hence Improved Project Management**

Decisions for Most Projects

- Most Usually made Qualitatively (ad hoc, gut feel, seat of the pants, shoot from the hip, best engineering judgment, etc.) – a *mental* integration process
- Sometimes made Semi-quantitatively
  - Have some data, perhaps Processed Statistically
  - Statistical Estimates Mentally Combined with Heuristics, Professional Opinions, Surrogate or Analog Data, *Assumptions*, and Prior Uncertainty about the Decision
  - Can be Better or Worse than Pure Qualitative Decisions
- Both are Difficult to Justify to Upper Management
- Outcomes of Decisions (Bad *and Good*) Often Second Guessed

Suppose …

- **You could Make a Decision *without Making any Assumptions*?**
- **You could Perform a *Completely Quantitative* Risk Assessment for Each Alternative?**
- **You could *Mathematically* Balance All Data, Professional Opinions, Prior Uncertainties, Surrogate or Analog Data, and Ancillary Information in that Quantitative Risk Assessment?**

Would that Help with those Important Decisions?

Presentation Synopsis

- Introduction to Real World Decision Examples
- Discussion of Project Decision Concepts
- The Role of Risk Assessments in Project Decisions
- Bayesian Estimation for Risk Assessments
- Closure with Real World Examples

Three Real World Decision Examples

- US Coast Guard C130 Preventative Maintenance (PM) Schedule
- NASA Bioastronautics Spaceflight Bone Fracture Risk Assessment
- NASA Space Shuttle and International Space Station Debris Avoidance

US Coast Guard C130 PM

- **New Flight Deck Cooling Turbine was Failing on Fleet of C130 Aircraft**
  - **Replacement Cost: $30K**
  - **Failure Terminated Missions and Risked Loss of Crew and Aircraft**
- **Performed a Single Refurbishment on Opportunity Basis**
  - **Cost: $500**
  - ***60 Refurbishments for a Single Replacement!***
- **Obvious Potential Cost Savings with PM**

USCG PM Decision Dilemma

- Had *only Five* Failures at 463, 538, 1652, 1673, and 2462 flight hours
- Opportune PM at 96 hours – no failure
- What PM Interval would Provide the Most Cost Savings?
- USCG was *Paralyzed*
  - Classical Statistical Assessment Unclear
  - Too Little Data
  - Wrong Answer could be Career Limiting
  - Failure to Use PM Increases Operating Costs

NASA Spaceflight Bone Fracture Risk

- **In Human Spaceflight History, no Astronaut/Cosmonaut/etc has Broken a Bone during a Mission**
  - **Known that Microgravity Reduces Bone Mineral Density Similar to Osteoporosis**
  - **Unknown How a Bone Fracture would Compromise a Mission or How it would Heal**
  - **Risk Assessment Limited to Purely Qualitative – Not Acceptable to NASA**
- **A Bone Fracture would be *Very Serious* during a Mars Mission**
- **Very Difficult to Verify Mitigation of the Risk with no Quantitative Measures of the Risk**

NASA Debris Avoidance

- **USSTRATCOM Tracks about 8,000 debris objects**
  - **Average Mass: 1,000 pounds**
  - **Typical Collision Velocity: 11.45 Km/s**
  - **Collision with Space Shuttle or ISS would be Catastrophic**
- **If Risk of Collision is Too High, Can Maneuver Shuttle or ISS to Avoid Debris**
  - **Causes Significant Operations Replanning and Costs**
  - **Seriously Compromises Microgravity Experiments**
- **Flight Rule Exists, Based on *Single Estimate* of Risk of Collision**

Decision Concepts

- ***Elements*** **of Every Decision**
  - **Alternatives**
  - **Consequences or Outcomes**
  - **Uncertainty**
  - **Experiments and Data**
  - **Decision Maker Risk Tolerance**
- **Every Decision: Based on Assessment of the Risk that the Alternative Selected will not Produce the Desired Consequences or Outcome**
- **Always want to Select the Alternative that you *Believe* has the lowest Risk of not Producing the Desired Outcome, i.e., has *the best chance of Producing the Desired Outcome***

What is Risk?

- **Best and Most Generic Definition:**
  an *Uncertain Future Consequence*
- **The *Measure* for Risk: Probability that Future Consequences will be Realized**
  - **Probability that Average Cost Savings using a *Y* hour PM Interval for Cooling Turbine for C130 Fleet is $*X*/hr**
  - **Probability that an Astronaut will Break a Bone during a Mars Mission**
  - **Probability of Loss of Shuttle or Station due to Debris Collision**
- **One Certainty: *The Consequence is Uncertain until Realized or OBE* (overcome by events)**

The Key to Good Decisions

- **Best Decisions Take into Account:**
  - ***All Data*, any and *All Information* on the Risk**
    - **Actual Event Data**
    - **Observations that an Event has not Happened by some time (*censored data*)**
    - **Events with Uncertainty as to when they Occurred (*truncated data*)**
    - **Expert Opinion, or Best Engineering Judgment**
    - **Surrogate or Analog Data (uncertain about applicability)**
  - **Prior Uncertainties about the Consequence or Outcome**
- **Proper *Quantitative Balancing* of All Relevant Information Produces the Best Risk Assessments**
- **This Enables the Best Alternative to be Selected**

The Risk Assessment is Key

- Quantitative *Statistical* Processing of all Relevant Data and Information, Considering Prior Uncertainties about the Alternatives
- Tells you *How Sure* Risk is at or below Some Level for each Alternative
  - *Nota Bene:* Not the Level of Risk – will always be unknown
  - The Probability that an Alternative's Risk of not Producing the Desired Outcome is at or below some Level
- The Alternative with the *Highest Assurance* that the Risk of not Producing the Desired Outcome is below some *Acceptable Level* is the One to Select
- This is Very Natural

There are Always Data

- **Sometimes for a Decision, you have *no* actual (Event) Data**
- **Example: 977+ Human Spaceflights in History, no Bones Ever Broken**
- **But, 977+ Human Spaceflights *without* a Bone Fracture Tells you a Lot about the Risk of Breaking a Bone in Space**

That's a lot of Data!

Those Usually Unused Data

- Recall we want to use *every scrap of Information available* to make the Best Possible Decision
  - Event Data (failures, USSTRATCOM tracking measurements)
  - Censored Data (opportune refurbishment time, 977+ no fracture flights)
  - Truncated Data (an event occurred, but not sure when)
  - Expert Opinion (heuristics are earned)
  - Surrogate or Analog Data (unsure about applicability to decision)
  - Prior Uncertainties about the Risk (if available)
- *Only Event Data* can be Used with Classical Statistical Procedures Taught in Engineering
- Decision Theory/Analysis uses Bayesian Estimation to enable use of all these Data sources in *Quantitative Risk Assessments*

Bayesian Estimation

- **Allows *Quantified Estimates* of Risk Using**
  - **All Possible Sources of Data**
  - **All Prior Uncertainties**
- **Does not Produce Single Values (point estimates) for Risk, Produces *Entire Distributions* for Risk**
  - **Distributions Can be Integrated to tell you *How Sure* Risk is below some *Acceptable Level* for each Alternative**
  - ***Ideal for Risk Assessment and Decisions***
- **Bayesian Estimation is the Risk Assessment Foundation for all Decision Theory and Analysis**
  - **Until Recently, limited applicability due to Math Complexity**
  - **New Numerical Techniques developed in mid 1990's Allow Full Bayesian Estimation for all Decisions for all Projects**

The Bayesian Process

- Select the *Aleatory* Model – Probability Distributions for Consequence or Outcome for Decision and any Uncertainties in Data (Expert Opinion, Surrogate Data)
  - Distribution Curves governed by Parameter Values
  - Our Uncertainty about the Consequences and Data *translates* to Uncertainty about these Parameter Values
- Develop the *Likelihood* Function: The Probability our data would be Obtained as a function of Aleatory Parameter Values – A Simple Probability Calculation
- Develop the *Prior* Uncertainty Distributions for the Parameter Values
- Multiply the Likelihood and the Prior
  - Produces the *Posterior* Distribution for the Parameter Values
  - *Balances the Information in the Data and the Prior Uncertainty*

The Bayesian Posterior

- **A *Balanced Reconciliation* of all Data and Information Sources and any Prior Uncertainty**
- **A *Joint Distribution* of the Parameters of the Aleatory Models**
    - **Usually *quite complex* mathematically**
    - ***Rarely Recognizable* as any Known Probability Distribution**
- **Modern *Monte Carlo* Methods are Used to Numerically Transform and Integrate the Posterior - Quantitative Risk Assessments**

The Bayesian Prior

- **A *Probability Distribution* for Uncertainty about the Consequences before Obtaining or Processing any Data**
  - **Must be *Translated* into Probability Distributions for Parameters of Aleatory Models**
  - **This Math can be *Quite Complex***
- **Recall my Claim about *Avoiding All Assumptions*?**
  - **Rather than Assuming Some Value to do the Math and Statistics, Can Use a Probability Distribution**
  - **If you cannot Find a Suitable Probability Distribution, You can Use a *Reference Prior***

The Reference Prior

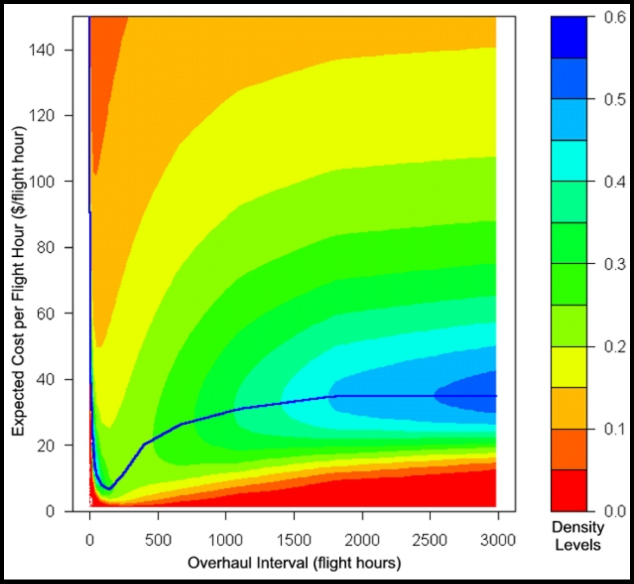
- **Presents a Model that Reflects *Ignorance* about the Consequence or Aleatory Model Parameters before Processing Data**
- **Provides a *Realistic* and *Valid Worst Case* Scenario**
  - ***Most Assumptions are Conservative* beyond this Worst Case Scenario**
  - **Realism for Reference Prior *Provable* Mathematically**
  - **Sets Reference Posterior**
- **Reference Priors *eliminate need* for Assumptions**
- ***Virtually Eliminates Second Guessing* – for that alone Well Worth Using**

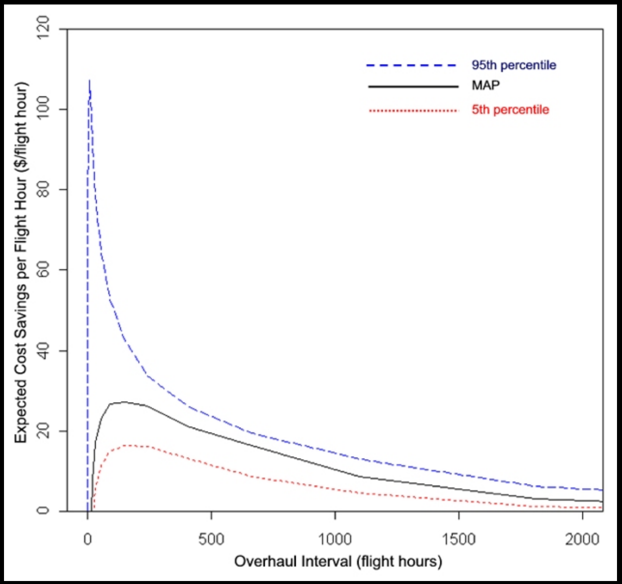
An Aside

- **Some Practitioners Believe when they Perform *Bayesian Updating*, that it is Bayesian Estimation**
- **Bayesian Updating is usually performed By Updating a *Classical Statistics* Point Estimate with New Data**
- **This Suffers the Same Problems and Limitations of All Classical Procedures**
  - **Assumptions are Usually Required**
  - **Lack of Knowledge of Believability of Point Estimate**
- ***Be Sure Bayesian Updating is not Being Used for Estimates!***

USCG C130 PM Decision

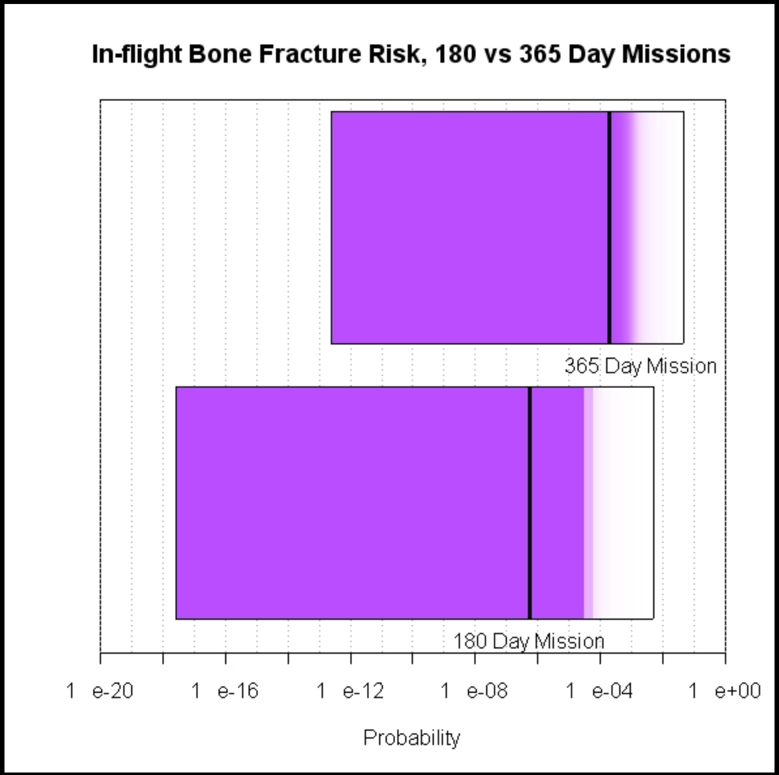
- Used Bayesian Estimation for 5 Failures and One Censored Datum (96 hour refurbishment) with Reference Priors
- In paper included on CD MAPINCOSE2002ArticleFinal.pdf
- USCG selected a PM interval and implemented for C130 Cooling Turbine based on these charts





NASA Spaceflight Bone Fracture Risk Decisions

- **Used to Quantify Increase in Fracture Risk in Extending ISS Missions to 365 Days**
- **Bandaid Charts:**
  - **From 5th to 95th Percentiles with Median (Dark Line)**
  - **Density of Color reflects Probability Density**
- **Note in *Bandaids*:**
  - **Increase in Medians**
  - **Substantial Probability Density at Very Low Risk Levels**
  - **Little Probability Density at Higher Risk Levels**



NASA Debris Avoidance

- **Current Flight Rule Implementation Uses *Single Point Estimate of Risk*, Not Bayesian Estimation**
- ***Dramatic* Improvements Possible Using Bayesian Estimation and Reference Priors**
  - **Allows Decision Strategies**
    - **Protect Operations – Maneuver only with High Assurance that Acceptable Risk of Collision is Exceeded**
    - **Protect Crew and Vehicle – Maneuver with Low Assurance that Acceptable Risk of Collision Exceeded**
  - **Would Produce Fewer Avoidance Maneuvers, Increase Safety, and Save Significant Resources**

Synopsis

- **Bayesian Estimation Allows Full Use of *all Data and Information* for Decision Making *without Assumptions***
- **With an Experienced Practitioner**
  - ***Easier and Quicker* than Classical Processes**
  - ***Easy to Learn* and become an Experience Practitioner, PM's Can Do at PC with Training**
- **For Important Decisions**
  - **Well Worth Hiring Experienced Practitioner**
  - **Well Worth Contracting Firms with Experienced Practioners**

Resources

- **For Training in Decision Making, Bayesian Estimation, and Risk Management, See webcampus.stevens.edu**
  - ***Decision and Risk Analysis for Complex Systems***
  - ***Probability and Statistics for Systems Engineers***
- **References, a book on Bayesian Estimation, relevant papers, and a Statistical Programming Tool are Provided on the CD**